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# SLOW SAND FILTRATION FOR DRINKING WATER TREATMENT: U.S. EXPERIENCE

by

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16. ABSTRACT

Alternatives to conventional water filtration plants (those using coagulation, flocculation, sedimentation, and rapid filtration) may be appropriate for some small water utilities. One such alternative is slow sand filtration. The U.S. Environmental Protection Agency has recently reexamined the use of slow sand filtration for the control of selected, regulated inorganic, microbiological, and organic drinking water contaminants. The research showed that slow sand filtration is an effective treatment technology that can easily be applied to small communities.

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# Slow Sand Filtration for Drinking Water Treatment:

# U.S. Experience

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## Introduction

The basic objectives of water treatment are to provide water to consumers in sufficient quantity, safe to drink, aesthetically acceptable, and at reasonable costs. Communities with an abundance of safe water have little trouble in meeting the above objectives, but communities that have a limited water supply or a source water that must be treated may be faced with many problems in meeting those objectives. These problems are amplified in small communities that have insufficient money or qualified personnel to construct and operate a water treatment facility.

One treatment technique that can be used by small communities having low turbidity surface waters to meet water treatment objectives is that of slow sand filtration. Slow sand filtration was used in the early days of water filtration but was largely abandoned in the USA with the advent of conventional coagulation-settling-rapid filtration techniques. Recently, interest in slow sand filtration has grown in the hopes that slow sand can be used in small communities.

Slow sand filtration offers many advantages over conventional filtration techniques, some of which include: 1) single step treatment that can improve the physical, biological and chemical quality of a low turbidity water, 2) easy to operate and lower operating costs with operating costs being principally labor rather than chemical or energy, 3) easy to construct and maintain with few mechanical parts 4) proven over decades of use, and 5) reproven with the reinvestigation of slow sand filters with modern analytical measurements. Disadvantages to slow sand filtration include: 1) higher capital costs incurred by the larger area of land required for construction, 2) inability of slow sand filters to treat high turbidity waters, and 3) the inability of slow sand filters to treat waters subject to many types of industrial wastes.

This paper will discuss the recent work that the U.S. Environmental Protection Agency (USEPA) has done in reinvestigating slow sand filtration for small communities. This work

will encompass both inhouse pilot studies and field projects using pilot scale filters and full scale facilities. Data will also be presented that shows cost information for slow sand filtration.

## Pilot Plant Research

The USEPA's Drinking Water Research Division (DWRD) recently examined slow-rate filtration on a pilot scale to evaluate its use by small water systems for the control of selected, regulated inorganic, microbiological, and organic drinking water contaminants. Two pilot scale filtration systems were constructed: a slow sand filter (Filter A) operated for 800 days and a second slow sand filter (Sand Filter B) in parallel with a slow-rate filter (Carbon Filter B) containing granular activated carbon (GAC), i.e., a slow carbon filter, operated for 200 days. A more detailed discussion of the units and the resulting data can be found in the literature.[1]

Both filtration systems were subjected to a variety of source water conditions. Typically, low turbidity surface water was spiked with raw sewage (a sewage-to-water volume ratio of 1:2500) to produce a water with a high level of coliforms. The sewage spike created conditions such that the influent coliform levels to filter A ranged from 15 to 10,000 colony forming units/100 mL. After the initial ripening period (with the exception of one period during the 800 days of operation) the effluent coliform counts were less than 1 CFU/100 mL. Heterotrophic bacteria reduction was typically 2 to 3 logs in magnitude on filter A. Turbidity levels for the influent to sand filter A ranged from 0.2 to 10 ntu. Once the filter passed the ripening stage, the effluent turbidity never exceeded 1.0 ntu and for the last 400 days of opeation were routinely below 0.35 ntu. Particle counting was also used to measure the effectiveness of the filter. A particle counter* capable of quantifying size and distributon of particles in the range of 2.5 to 150 um diameter in an aqueous sample was used to analyze both the influent and effluent. Filter A displayed one to two log reductions of Giardia-cysts-sized (7-12 um) particles and tended to show greater reductions as the filter became clogged. Counts of other particle sizes exhibited similar reductions. Profile sampling showed only minor reductions in particle counts below the top few cm of sand. In order to compare organic removals, sand filter A was sampled during the first

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[1]Fox, K. R., et al. Pilot-Plant Studies of Slow-Rate Filtration. Journal AWWA, Vol. 76, No. 12, page 62, (December 1984).

*HIAC Particle Size Analyzer, Model PC-320, CMH-150, Pacific Scientific Co., Montclair, Calif., USA. (Mention of commercial products does not imply indorsement by USEPA).

200 days and displayed average removals of 19 and 18 percent for total organic carbon (TOC) and seven-day trihalomethane formation potential (THMFP), respectively.

The GAC used in carbon filter B was a commonly available water-grade mix (12 x 40 mesh coal base) with an effective size ranging from 0.55 to 0.65 mm. Because this size is much larger than that typically used for slow-rate filtration media, particulate penetration was anticipated. Carbon filter B was subjected to a source water with a turbidity ranging from 0.4 to 23 ntu. Even with the high influent turbidities and the larger effective size of the carbon media, carbon filter B lowered the turbidity to below 1 ntu and routinely to below 0.5 ntu. After the initial ripening period, one to two log reductions were observed in heterotrophic plate counts and a one to three log reduction in coliform densities with carbon filter B. Comparison of filters A and B showed that bacterial control improved as the effective size of the sand decreased, as previously reported by Hazen.[2] Control of organics by activated carbon filter B was very effective but, as expected, was dependent on time. Mean TOC and seven-day THMFP removals were 88 and 97 percent, respectively. Periodic profile sampling showed a time dependent wavefront movement of organics through the adsorbent.

## Survey Results

A recent survey of 27 slow sand filtration plants in the United States revealed data that supports work that has been done by researchers.[3] Survey results demonstrated the long life of existing slow sand plants and the recent increase in interest in slow sand filtration with 56 percent of the plant surveyed being over 50 years old and with 33 percent of the plants constructed in the past 25 years. One primary concern in operating a slow sand filter is to have a low turbidity water source to prevent rapid filter clogging. The survey showed that 74 percent of the plants used lakes or impounded water supplies, 4 percent used ground water and the remainder used flowing water supplies. At all plants surveyed, the average raw water turbidity never exceeded 15 ntu (average influent turbidity of all plants was 4.0 ntu).

The survey also showed that 62 percent of the plants were serving communities with fewer than 10,000 persons and only 11 percent of the plants were in communities with populations that exceeded 100,000. Design parameters for the surveyed plants were

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[2]Hazen, A. The Filtration of Public Water Supplies. John Wiley & Sons, New York (3rd ed., 1913).

[3]Slezak, L.A. & Sims, R.C. The Application and Effectiveness of Slow Sand Filtration in the United States. Journal AWWA, Vol. 76, No. 12, page 38, (December 1984).

well within the guidelines set by Huisman and Wood[4] and others. The mean filtration rate was 0.15 $m^3/h/m^2$, mean sand depth was 84 cm, mean sand effective size was 0.38 mm, and the mean sand uniformity coefficient was 2.3. Operational characteristics of the plants were also tabulated. The survey showed that 62 percent of the plants employed 2 or less operators, while 12 percent of the plants had more than 10 employees. Only a few of the plants surveyed utilized power tractors for filter scraping (the majority of the plants used hand shovels).

## Field Research

In conjunction with the inhouse pilot scale research, EPA initiated several field studies to evaluate slow sand filtration. The studies were done utilizing both pilot scale systems and a full scale slow sand filter that was not being used. The principal objectives of these field studies were to evaluate slow sand filters for the removal of *Giardia lamblia* cysts, bacteria, turbidity, and trihalomethane formation potential. Operational data were collected during the course of these projects to define the hours and costs associated with operating and maintaining slow sand filters. An evaluation also was made of filtered water quality both before and after a filter was scraped to determine how a filter's efficiency was affected by scraping.

*Giardia* cyst removal was shown to be affected primarily by the biological maturity of the filter and by low temperatures.[5,6] *Giardia* cysts were spiked into the influent water in two of the field studies. At both locations, removal rates were observed and related to the hydraulic loading rate, temperature, sand size, sand bed depth, and to schmutzdecke removal. *Giardia* cyst removal was very dependable, and removals exceeding 99.9 percent were seen during warm water and biological mature filter conditions. Removals percentages decreased during cold weather (< 7°C), but removals still exceeded 99 percent during non-optimum treatment conditions. Sand size (below 0.278 mm effective size), sand bed depth, and hydraulic load rate had little or no affect on *Giardia* cysts removal and greater than 99.9 percent removal was observed under varying conditions. The high removal percentages under most conditions is due in part to the large size of the *Giardia* cysts (7 - 12 um).

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[4]Huisman, L. & Wood, W.E. Slow Sand Filtration, World Health Organization, Geneva, Switzerland (1974).

[5]Bellamy, W.D. et al., "Filtration of *Giardia* Cysts and Other Substances, Volume 2. Slow Sand Filtration." EPA-600/2-85/026 U.S. Environmental Protection Agency, Cincinnati, Ohio, 1985.

[6]Pyper, G.D., "Slow Sand Filter and Package Treatment Plant Evaluation: Operating Costs and Removal of Bacteria, *Giardia* and Trihalomethanes," U.S. Environmental Protection Agency, Cincinnati, Ohio, 1985. NTIS PB85-197051/AS.

Coliform and heterotrophic plate count bacteria removals were not as efficient as Giardia removal and were affected by varying operating conditions. Coliform removals by slow sand filtration were high and were approximately 99 percent during optimum operational conditions. The coliform removals percentages were affected by cold temperatures, increased hydraulic loading rates, larger effective sized sand, shallower bed depth, sand scraping, and resanding. Under various adverse conditions, total coliform removals ranged as low as 80 percent to over the 99 percent removal under optimum conditions. A new slow sand filter was capable of removing only 60 percent of the total coliforms at start-up until the filter biologically matured.

One of the pilot scale filters contained a sand with an effective size of 0.615 mm.[7] Total coliform removal by this filter was lower than by filters with a smaller sand. At ambient water temperatures of 17°C, this filter achieved 92.8 percent removal of total coliforms. This removal was lowered even further to approximately 83 percent when the source water temperature was reduced to 5°C. The filters containing the smaller sand also showed a decrease in total coliform removals with reduced source water temperatures, but still maintained an average of 90 percent removal at 5°C. A shallower bed depth also lowered the total coliform reduction. One of the test filters housed a bed depth of only 48 cm (as compared to 97 cm in the other filters). This filter demonstrated an average of 95.3 percent removal for total coliforms. Hydraulic loading also affected coliform reduction and when the flow rate was tripled from 0.12 m/hr to 0.40 m/hr, coliform removals decrease from 99 percent to 95.7 percent.

At the full scale plant that was experimentally used, coliform removal was not as efficient as in the pilot units. Total coliform removal averaged around 80 percent for the test periods (various intervals over two years of operation). The source water quality had extreme variations in coliform counts with very high counts being present followed by very low values. The effluent from the slow sand filter did not show an immediate improvement in water quality when low coliform counts were present in the source water and thus low removals percentages would appear when influent water of good quality was applied following application of influent water of poor quality.

Heterotrophic plate count bacteria removal by slow sand filtration was more erratic that the coliform reduction data. This is due in part to the fact that a slow sand filter is also a biologically active community and that sloughing of bacteria from an active filter can occur. Removal percentages average 89 percent for heterotrophic plate count data. When high levels of heterotrophic

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[7] Bellamy, op cit.

plate count bacteria were present in the source water (5 X $10^5$ CFU/mL), removals exceeded 99 percent. Removals were not as high when the influent heterotrophic plate count was lower, but effluent counts generally ranged from 8 to 200 CFU per milliliter.

Good removal of turbidity and particle count data were seen in most of the field studies. Poor reduction in turbidity was seen at one test site, which was attributed to an abundance of extremely small particles in the source water. Slow sand filters were capable of lowering the turbidity to below 1 ntu when the source water quality did not routinely exceed 15 ntu and was not comprised of extremely small colloidal material. Under optimum conditions, effluent turbidities were routinely below 0.3 ntu at the experimental full scale plant.

Trihalomethane formation potential was also evaluated at one field site and reductions similar to the inhouse studies were observed. The full scale unit showed a reduction of around 10 percent in formation potential. This removal is low and in areas where trihalomethane formation is a problem, slow sand filtration is probably not an acceptable treatment technique.

During routine operation, slow sand filters do not need much manpower for proper operation. The daily operational procedures such as monitoring flow rates, measuring head loss, analyzing turbidity samples, and recording appropriate operational data only take a relatively short period of time. The labor requirements rise dramatically when a slow sand filter must be taken out of service and cleaned. Data was collected from 7 operating slow sand filters to attempt to quantify the labor requirements for both routine operation and for filter scraping.[8] An attempt was also made to relate the frequency of filter scraping to various operating conditions such as raw water quality, hydraulic loading rate, and sand size.

At one of the seven New York plants studied, one inch of sand was removed from the top of the filter manually during filter scraping and then transported from the filters with motorized buggies or by hydraulic transport. The man-power required under these conditions was approximately 5 man-hours per 1000 $ft^2$ (92.9 $m^2$) of filter plan area. More man-hours would be required where the sand would be transported by hand drawn carts. Resanding, where new sand is placed in the filter to replace several scrapings of sand, normally required approximately 50 man-hours per 1000 $ft^2$ (92.9 $m^2$) (replacing 6 - 12 (15 - 30 cm) inches of clean sand).

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[8]Letterman, R.D. and Cullen, T.R., "Slow Sand Filter Maintenance Costs and Effects on Water Quality." U.S. Environmental Protection Agency, Cincinnati, Ohio, 1985. NTIS PB85-199669/AS.

After resanding or routine scraping, a re-ripening period is normally necessary before the slow sand filter is effective. In both the pilot scale inhouse work and pilot scale field studies, this ripening period was not evident using turbidity, particle count data, or bacteria data as the water quality measurement. The data collected from the full scale plant did show a deterioration in water quality following filter scraping or resanding. This discrepancy in results is probably due to the fact that a full scale filter is disturbed more during scraping than a pilot unit. In a full scale filter, workers are walking across the sand and possibly driving vehicles across the sand during the maintenance operations, while in a pilot scale unit the maintenance operations can be performed with minimal disturbance to the filter.

The length of the ripening period following resanding or scraping ranged from 6 hours to 2 weeks in duration (based on turbidity and particle count data). The predominate water quality factor enfluencing the length of the ripening period was the nature of the particulate matter in the raw water. The data collected did not show any evidence that source water temperature, scraping methodology, or even prechlorination had an effect on the presence or absence of a ripening period.

## Slow Sand Filtration Costs

DWRD has conducted several studies in order to acquire a more complete understanding of the costs associated with constructing and operating slow sand filters. Letterman studied the operating and maintenance costs of seven slow sand filters in the U.S., with particular emphasis on the labor and maintenance costs for sand scraping and replacement.[9] Pyper studied a slow sand filtration system at McIndoe Falls, Vermont for a period of two years emphasizig operating costs, and removal of bacteria, *Giardia* and trihalomethanes.[10] Gumerman et. al. have developed capital and operating and maintenance costs for numerous small system technologies including slow sand filters.[11]

This paper presents cost equations, based on the original data developed by Gumerman et. al., for two types of slow sand filters: a cast-in-place, concrete structure; and, an uncovered earthen berm structure. Costs presented are not necessarily for a complete plant. For example, not included are cost data for

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[9] *Ibid*.

[10] Pyper, *op cit*.

[11] Gumerman, R.C., et. al., "Estimation of Small System Water Treatment Costs," U.S. Environmental Protection Agency, Cincinnati, Ohio, Nov. 1984. NTIS PB 85-161644

chlorination and raw water pumping. Figures 1 and 2 are typical schematics for the covered and uncovered facilities respectively.

The design criteria upon which the cost equations were developed for both types of filters are given in Table 1. It was assumed that one extra filter was necessary for firm capacity.

TABLE 1. DESIGN CRITERIA FOR SLOW SAND FILTERS

| Criteria | Values |
|---|---|
| Filtration Rate | 70 gpd/sq ft (0.12 M/hr) |
| Depth of Sand | 3.5 ft (1.07 M) |
| Depth of Support Gravel | 1 ft (0.30 M) |
| Supernatant Box Depth | 4.0 ft (1.22 M) |
| Clear Water Storage | 12 hours production |

## Construction Costs

Figure 1 is a schematic of the covered slow sand filter, and illustrates what components are included in the construction costs. The concept of the covered filters incorporates below-grade concrete structures with beam and slab covers. All piping is either cast iron or steel and is also below grade. Because slow sand filters operate most efficiently at a constant filtration rate, flow meters for each filter and a below-grade concrete clear water reservoir are included. The rate of flow through the filter is established by an individual control valve for each filter. Also included in the concept is an effluent flow control structure. This structure has two principal purposes: (1) to prevent the water level in the sand filter from inadvertently being drawn down below the filter surface; and (2) to aerate the filter effluent to release any odors which may be present. Included in these costs is excavation to allow these structures to be constructed below grade as indicated on Figure 1, a pump to allow backfilling of filters after cleaning, and a clear water reservoir.

Figure 2 is a schematic of an uncovered slow sand filter and illustrates components included in the construction costs. The concept of the uncovered filters incorporates on-grade, clay-lined structures formed by earthen berms. All piping is PVC and is below grade. A steel tank reservoir, an effluent flow control structure, a single flow meter to measure total plant flow, and a pump for filter backfilling are also included.

Equation (1) relates the construction cost of a covered slow sand filter to the number of square feet in the slow sand filter:

$$CC = 148000 + 74\ SQFT^{1.04} \quad (1)$$

where

CC = Total construction cost for covered filter system in 1983 U.S. dollars, excluding administrative and engineering fees, interest during construction, etc.

SQFT = Total filter area in square feet of all filters combined

Equation (2) presents the construction costs for uncovered slow sand filters:

$$CU = 163000 + 14\ SQFT^{1.08} \quad (2)$$

where

CU = Total construction cost for an uncovered filter in 1983 U.S.dollars, excluding administrative and engineering fees, interest during construction, etc.

SQFT = Total area in square feet for all filters combined.

Operating and Maintenance Costs

Operation and maintenance requirements for slow sand filters are usually minimal. The only periodic adjustment required is that of a control valve, to maintain the desired flow through the filter in response to the increasing headloss through the filter. Sand bed cleaning, and berm maintenance for the uncovered slow sand filter, are the only major maintenance tasks. Manual sand bed cleaning is assumed. Maintenance material includes replacement parts associated with filter operation and sand cleaning. Sand replacement cost is not included. Addition of a mechanical sand bed scraper would increase the capital costs by 3 to 13 percent and correspondingly decrease operation and maintenance costs by 8 to 26 percent depending upon plant size.

Process energy requirements include only the backfilling pump, which because of the infrequent use of the pump are negligible. Building energy requirements are for heating, lighting, and ventilation of the control and storage building. The fuel requirement is for the mechanical sand bed cleaner and berm maintenance equipment.

Maintenance material requirements were estimated from anticipated costs of replacement parts and replenishment of the minor amount of consumable supplies involved in daily operation. The cost of replacement sand is not included. Experience from operating filters suggests that careful cleaning allows resanding to be necessary as infrequently as every 10 years.

Labor requirements were developed assuming the filters operate unattended. They include a short daily inspection and control valve adjustment, daily turbidity measurements, quarterly cleanings of each filter by hand, normal repair and replacement of equipment and berm maintenance for the uncovered filters. No allowance for administrative laboratory work is included.

Equation 3 shows the building energy costs for both covered and uncovered filters:

$$BE = 4714\ SQFT^{0.24} \quad (3)$$

where

BE = Building Energy in kilowatt hours per year for both covered and uncovered filters:

Equation 4 shows the maintenance costs for covered filters:

$$MC = 421 + 1.33\ SQFT^{0.90} \quad (4)$$

where

MC = Maintenance Cost for a covered filter system in 1983 U.S. dollars per year.

Equation 5 shows the maintenance costs for uncovered filters.

$$MU = 371 + 0.015\ SQFT^{1.16} \quad (5)$$

where

MU = Maintenance Cost for an uncovered filter system in 1983 U.S. dollars per year.

Equation 6 shows the labor hours for a covered filter:

$$LC = 161 + 0.24\ SQFT^{0.86} \quad (6)$$

where

LC = Labor hours per year for a covered filter system.

Equation 7 shows the labor hours for an uncovered filter.

$$LU = 179 + 0.47\ SQFT^{0.80} \quad (7)$$

where

LU = Labor hours per year for an uncovered filter system.

Equation 8 shows the fuel costs for uncovered filters:

$$F = 2.83\ (SQFT)^{0.39} \quad (8)$$

where

F = Gallons of diesel oil per year for an uncovered filter.

These equations can be used to estimate the various cost components associated with both covered and uncovered slow sand filters.

## Summary

The pilot plant studies, field research projects, and the surveys have shown that slow sand filtration can be a relatively easily operated and effective treatment process for small systems requiring a treatment facility for a low turbidity surface water. The cost information presented can be used to predict the costs associated with slow sand filtration. Although slow sand filtration is not a water treatment panacea, slow sand can be utilized to help small communities in treating drinking water effectively and cost efficiently.

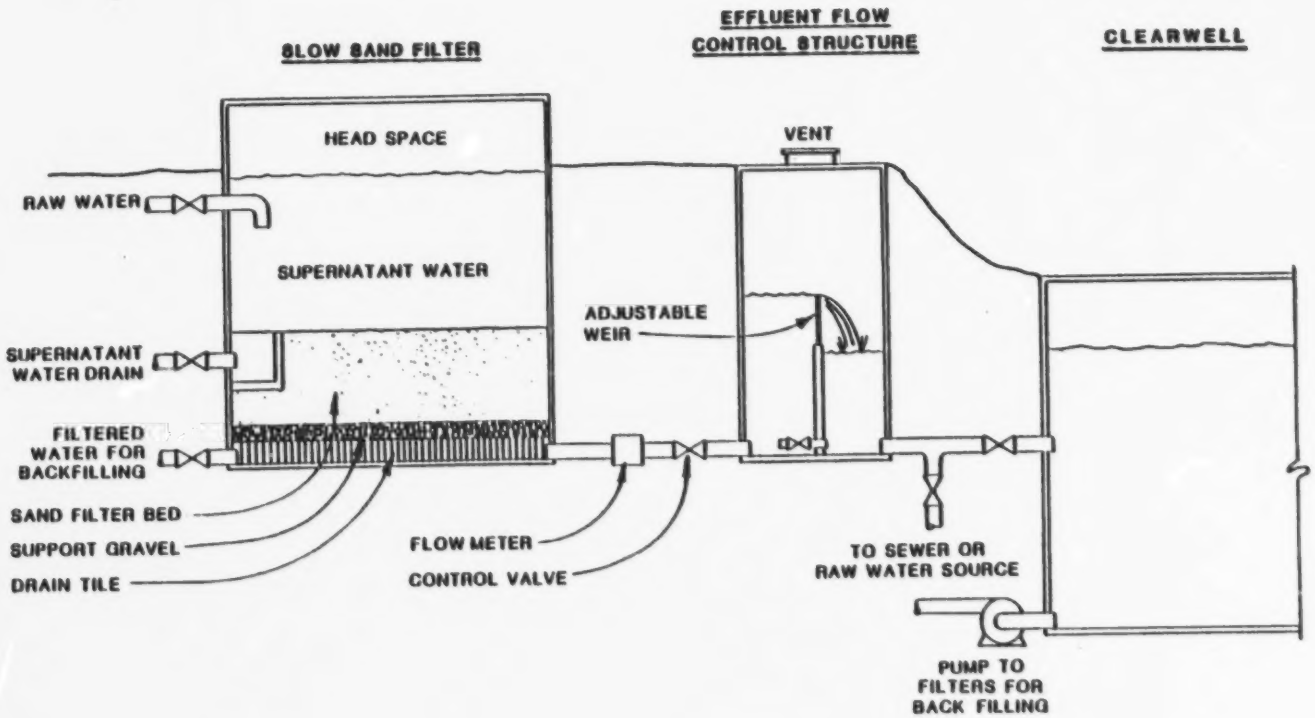


**FIGURE 1. TYPICAL COVERED SLOW SAND FILTER INSTALLATION.**

Reprinted from Gumerman, R.C., et. al., "Estimation of Small System Water Treatment Costs." U.S. Environmental Protection Agency, Cincinnati, Ohio, Nov. 1984. NTIS PB 85-161644.

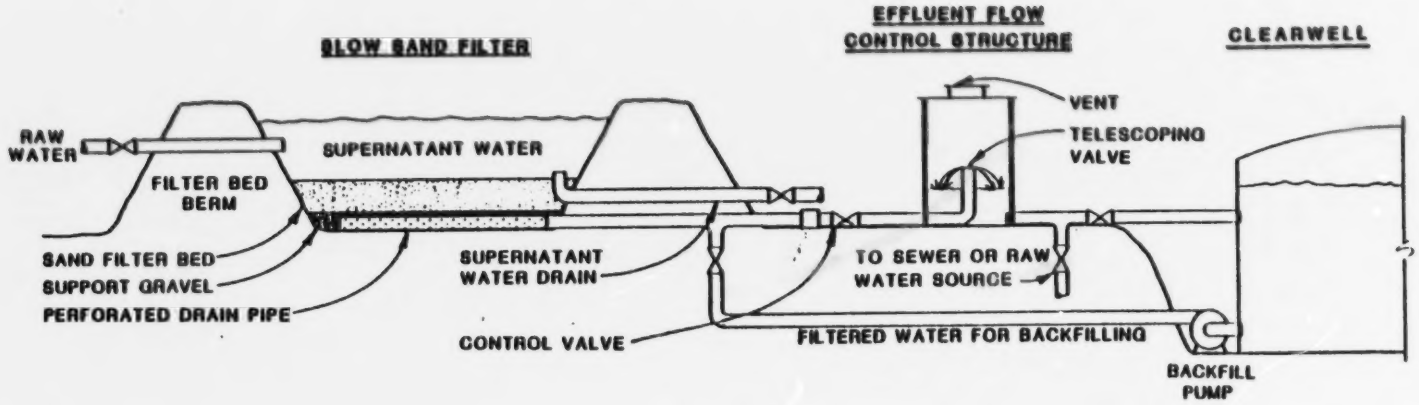


**FIGURE 2. TYPICAL UNCOVERED SLOW SAND FILTER INSTALLATION.**

Reprinted from Gumerman, R.C., et. al., "Estimation of Small System Water Treatment Costs." U.S. Environmental Protection Agency, Cincinnati, Ohio, Nov. 1984. NTIS PB 85-161644.